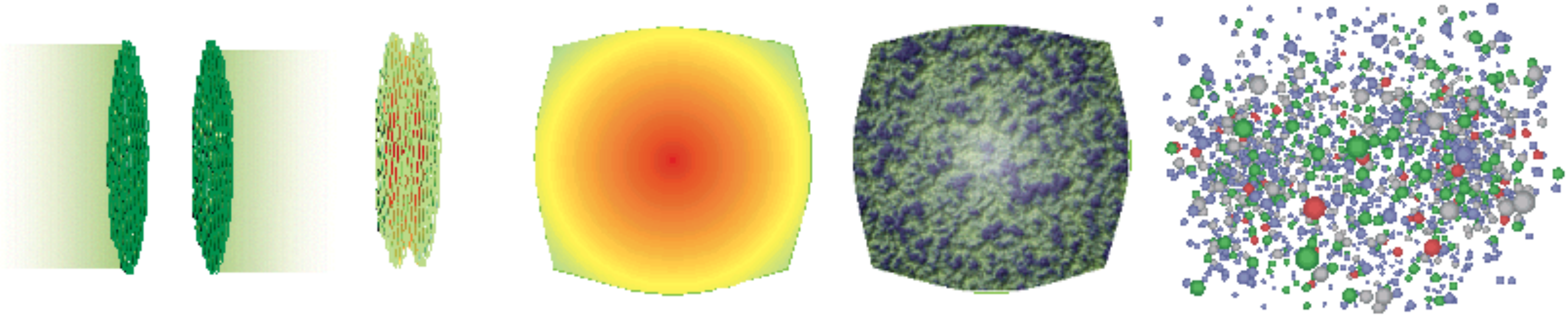
Thermal Radiation (?) Workshop

based on work with M. Chiu T. Hemmick, A. Leonidov, J. Liao, V. Khachatryan



CGC

Initial Singularity

Glasma

Thermalized sQGP

Hadron Gas

<-------------sQGP ------------->

The Space-Time Evolution of Heavy Ion Collisions

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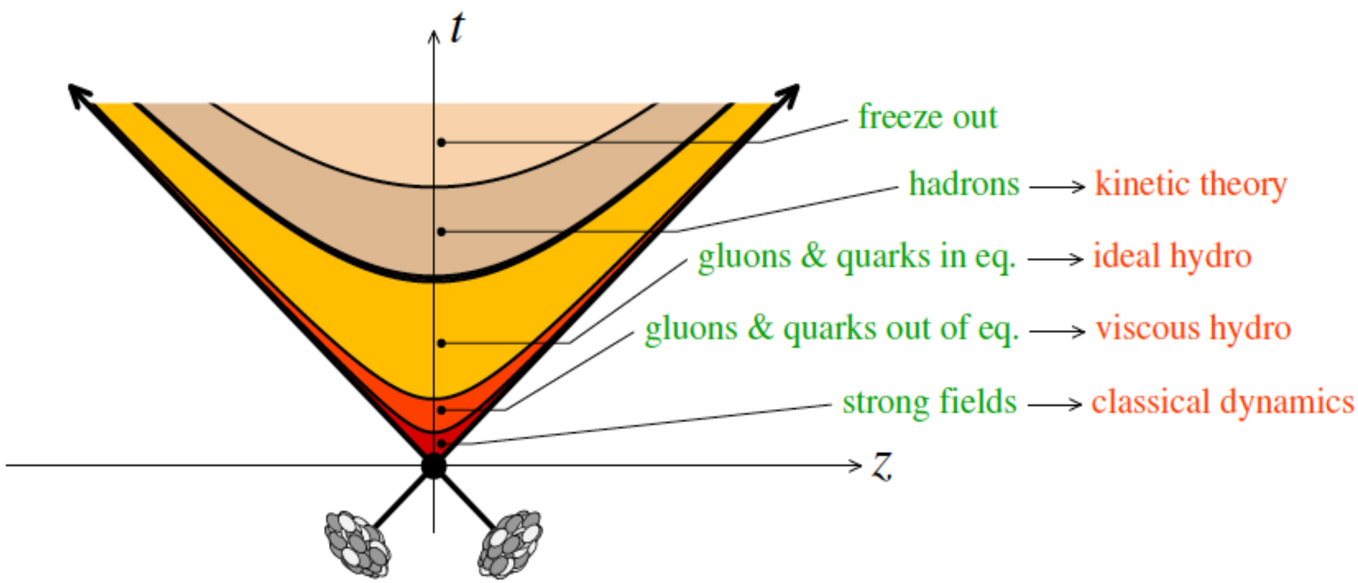
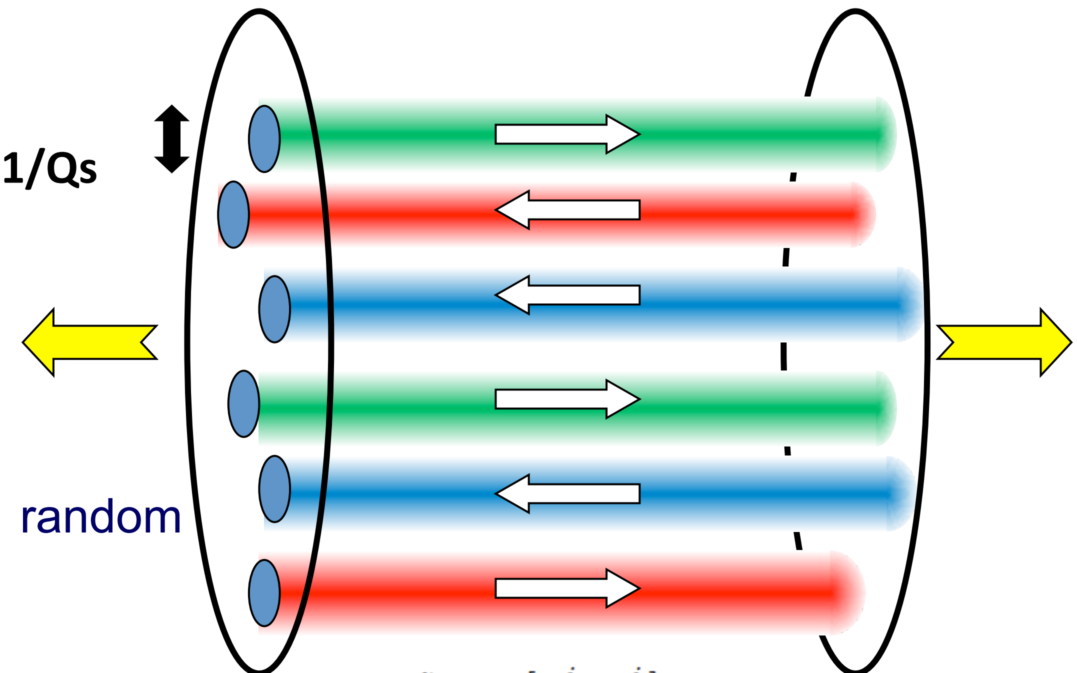


Color Glass Condensate:
The High Density Gluonic States of a high energy hadron that dominate high energy scattering.

Glasma:
Highly coherent gluon fields arising from the Glasma that turbulently evolve into the thermalized sQGP while making quarks

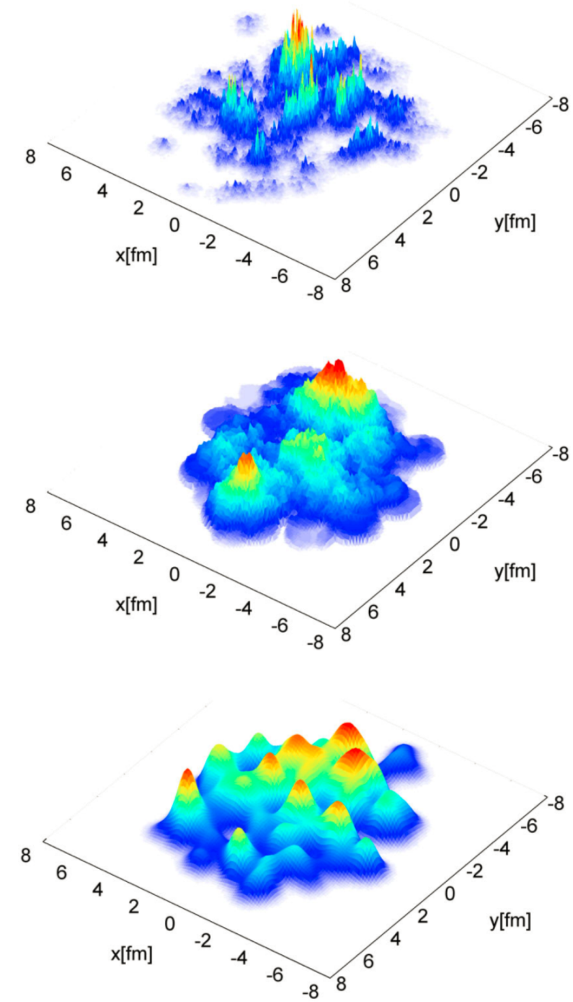
Thermalized sQGP:
Largely incoherent quark and gluons that are reasonably well thermalized

The Glasma



$$E^z = ig[\alpha_1^i, \alpha_2^i]$$
$$B^z = ig\epsilon^{ij}[\alpha_1^i, \alpha_2^j].$$

Typical configuration of a single event
just after the collision



Highly coherent colored fields:
Stringlike in longitudinal direction
Stochastic on scale of inverse saturation momentum in transverse direction
Multiplicity fluctuates as negative binomial distribution

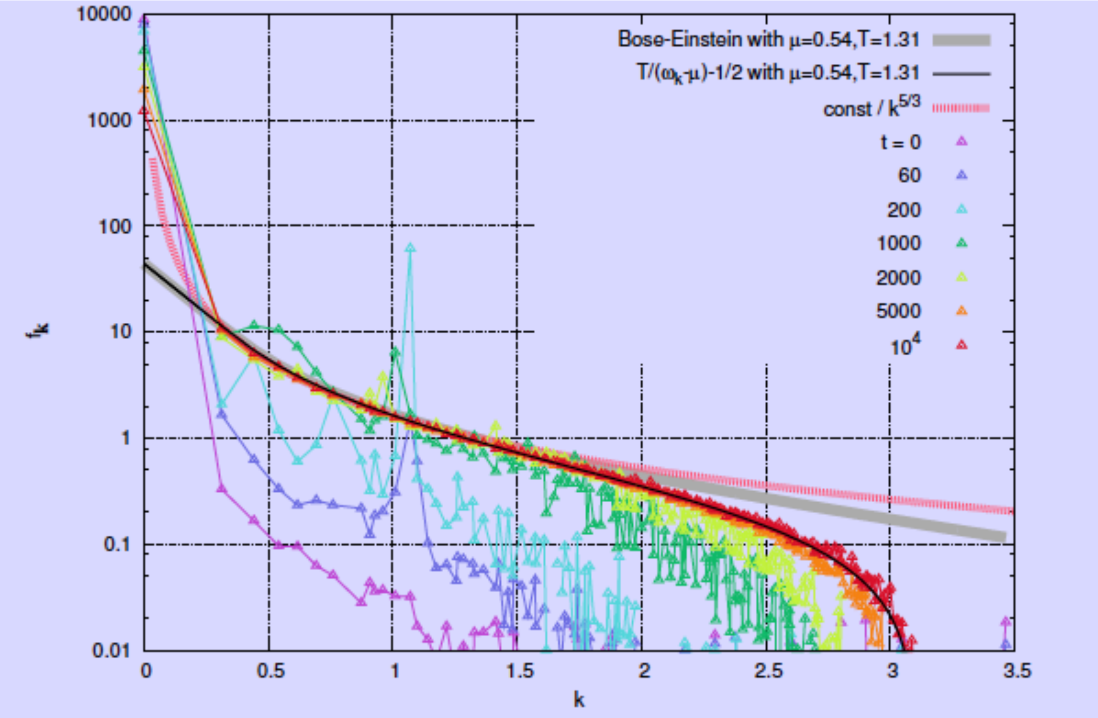
The Glasma:

Weak coupling but strongly interacting due to coherence of the fields
In transport or classical equations, the coupling disappears!
Two scales

$$\Lambda_{coh}(t_{in}) \sim \Lambda_{UV}(t_{in}) \sim Q_{sat}$$

But it takes time to separate the scales and make a thermal distribution

$$\Lambda_{coh}(t_{therm}) \sim \alpha_s \Lambda_{UV}(t_{therm}) \sim \alpha_s T_{init}$$



How long does it take to thermalize?

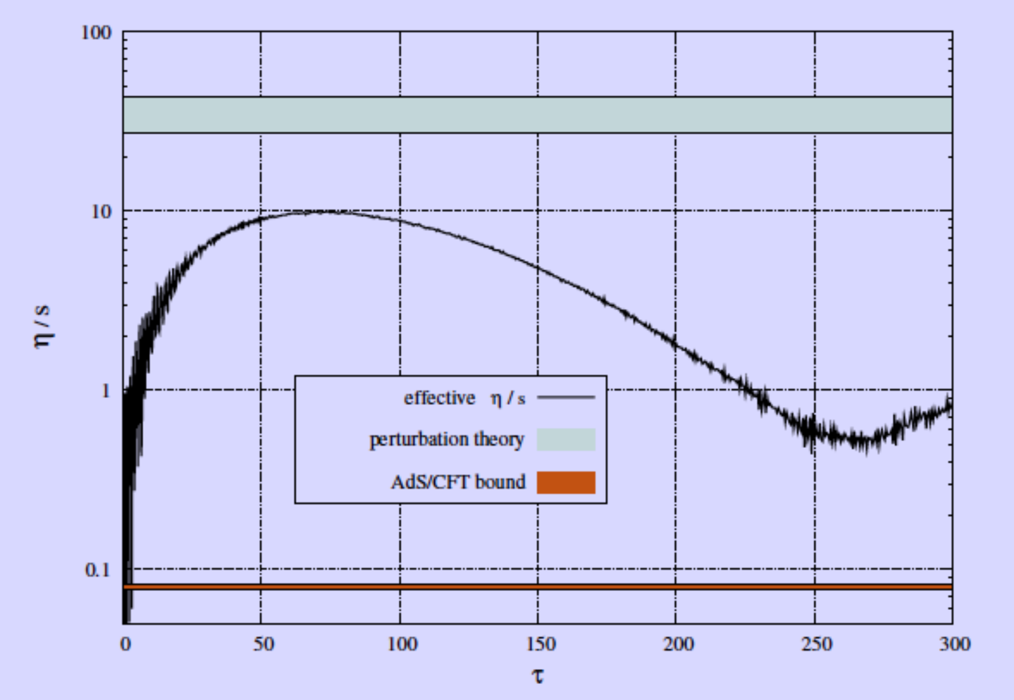
Are there Bose-Einstein Condensates formed?

For how long is the system in homogeneous with longitudinal pressure not equal to transverse?

Can we measure a difference between longitudinal and transverse pressure?

Gelis: Scalar field

Order parameters: Electric and magnetic confinement



In scalar field theory:

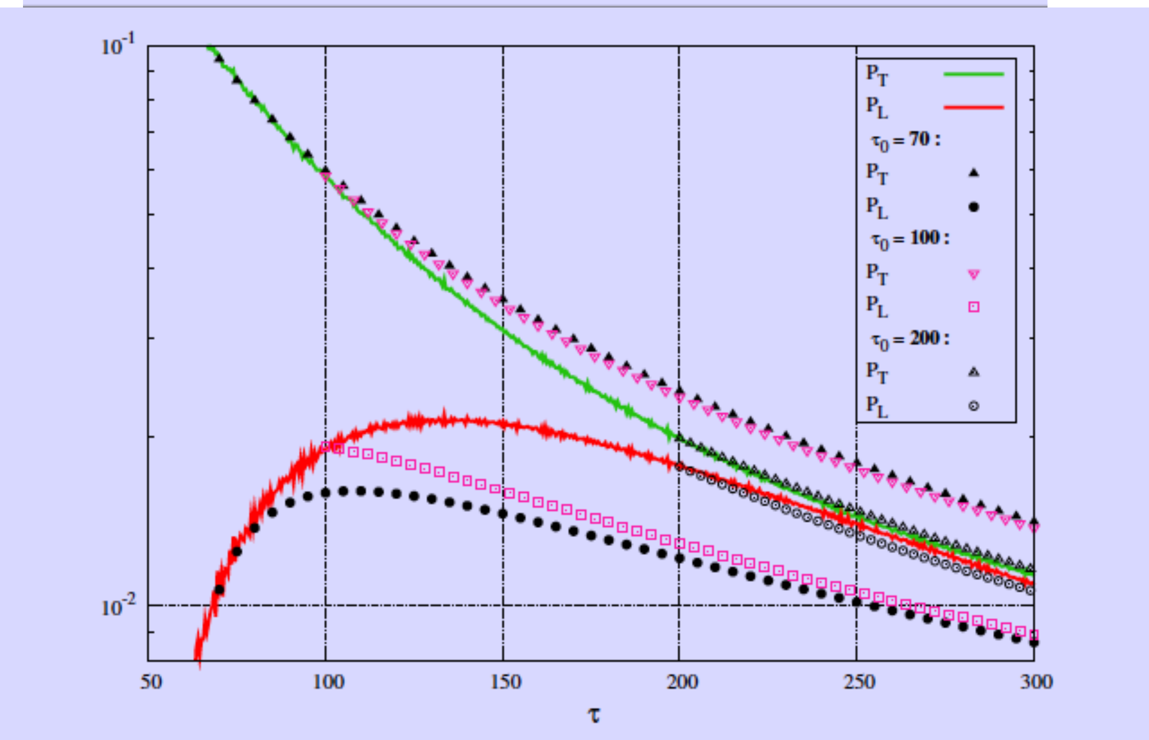
Smallish viscosity

Eventual equilibration of longitudinal and transverse pressure

Longish time for thermalization

Yang Mills theory with realistic numbers?

What condenses?



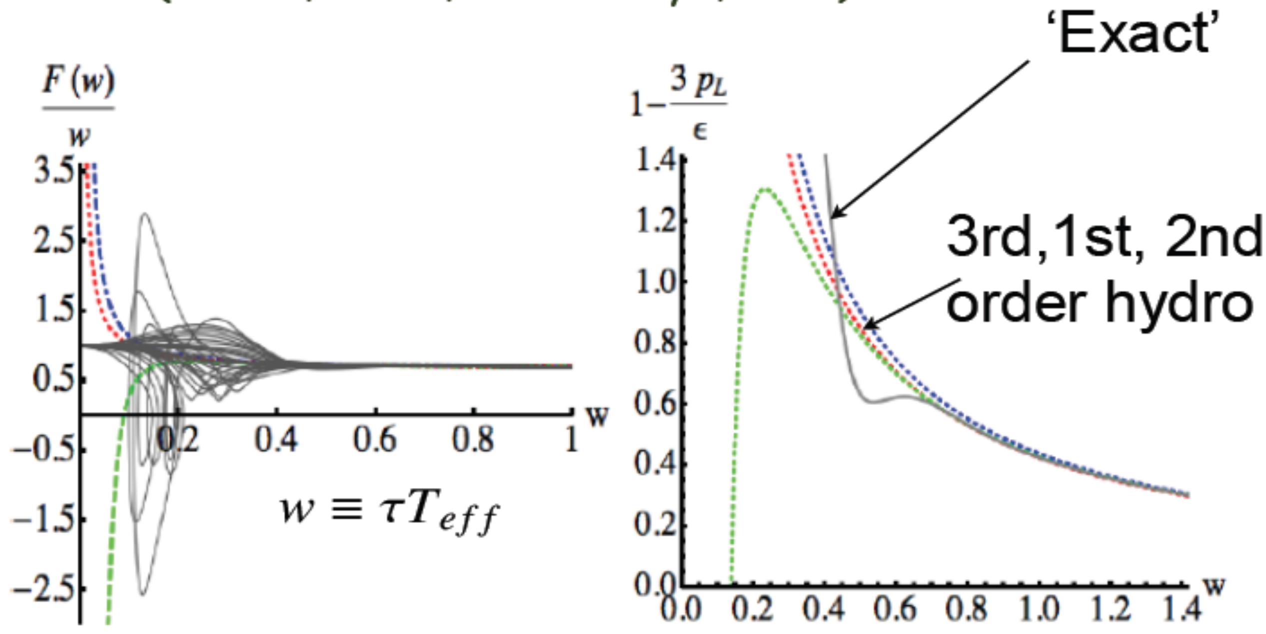
The Glasma and turbulent coherent fields is generically a new type of matter:

There may be genuinely new phenomenon associated with electric and magnetic confinement and perhaps superfluidity

Vacuum ~ Turbulent Fluctuations?

Holographic description of a boost invariant plasma

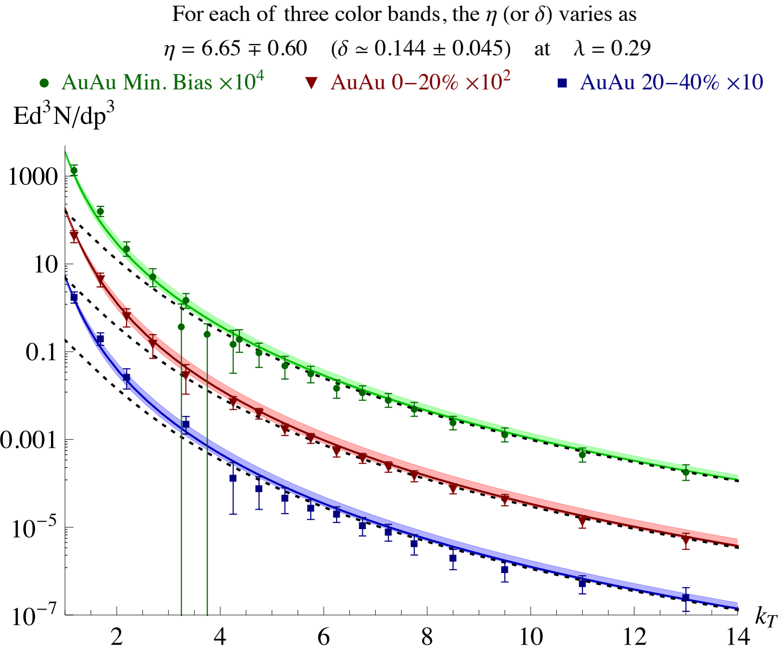
(Heller, Janik, Witaszczyk, 2011)



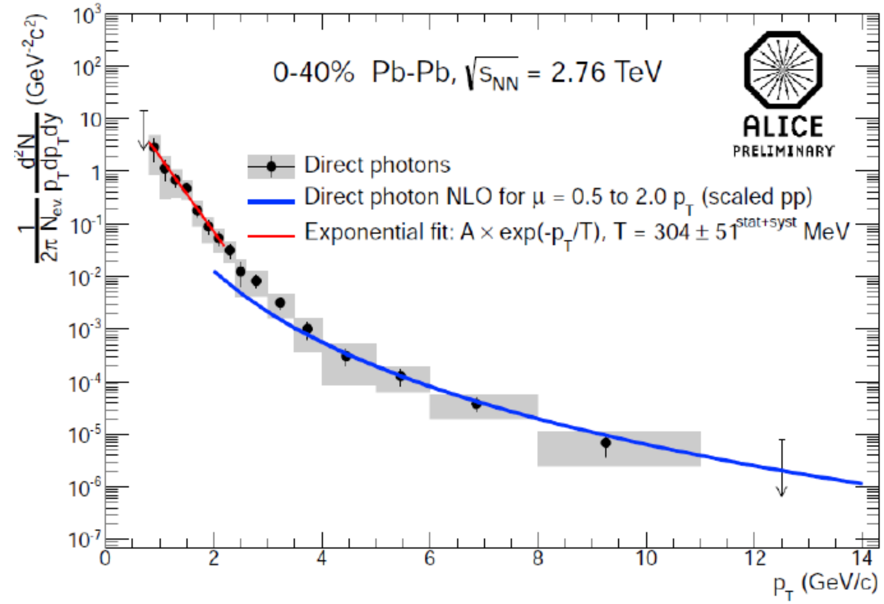
Viscous hydro can cope with partial thermalization, and large differences between longitudinal and transverse pressures

In fact, there is little experimental evidence that complete local equilibrium is reached in nuclear collisions

The Glasma may be a nearly perfect fluid, even though it is not a thermalized sQGP. It is certainly a sQGP



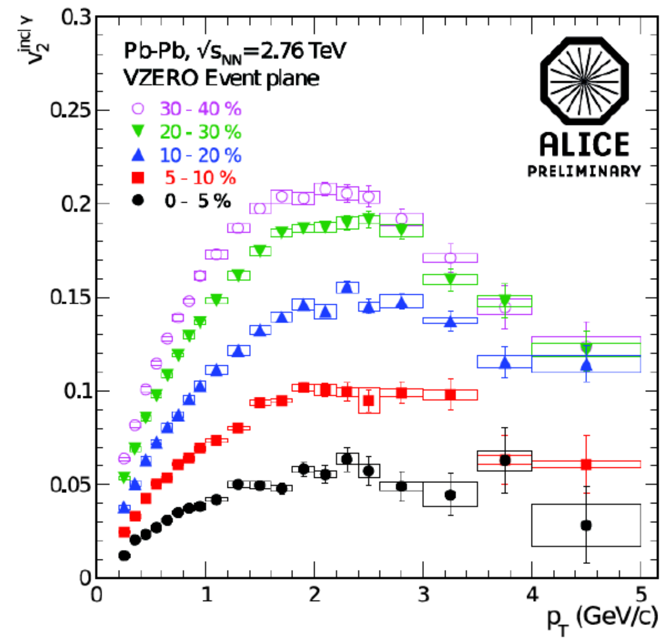
Photon excess in Phenix as function of centrality and pT



Similar photon excess seen in Pb-Pb at Alice

Confirmed
High pT suggests photons comes from early time
V2
and
geometric scaling of multiplicity dependence seen in Phenix suggest photons did not arise from a very hot thermalized QGP

Large Flow seen in both Phenix and Alice



Geometric scaling of photon distributions:

$$\frac{1}{\sigma}\ \frac{dN}{d^2p_T} = F(Q_{sat}/p_T)$$

σ Is the geometrical overlap area $\sim N_{part}^{2/3}$

$$Q_{sat} \sim N_{part}^{1/3}\ (\Lambda_{QCD}/p_T)^{\lambda} \qquad \lambda \sim .3$$

Power law fit to pT spectrum give a power of about 8, and therefore roughly a N_{part}^2 dependence on centrality Fit is shown on previous figure

Rate for Glasma emission is

$$\frac{dN}{d^4x dy d^2k_T} = \frac{\alpha}{\pi}\Lambda_s \Lambda g(E/\Lambda)$$

Can fold together with expected power law evolution of ultraviolet and infrared scales, and power law found in data is not unreasonable, given current uncertainty in Glasma evolution, Find a power law behaviour

In the Glasma,

$$N_{gl} \sim \Lambda_s \Lambda^2 / \alpha_s$$

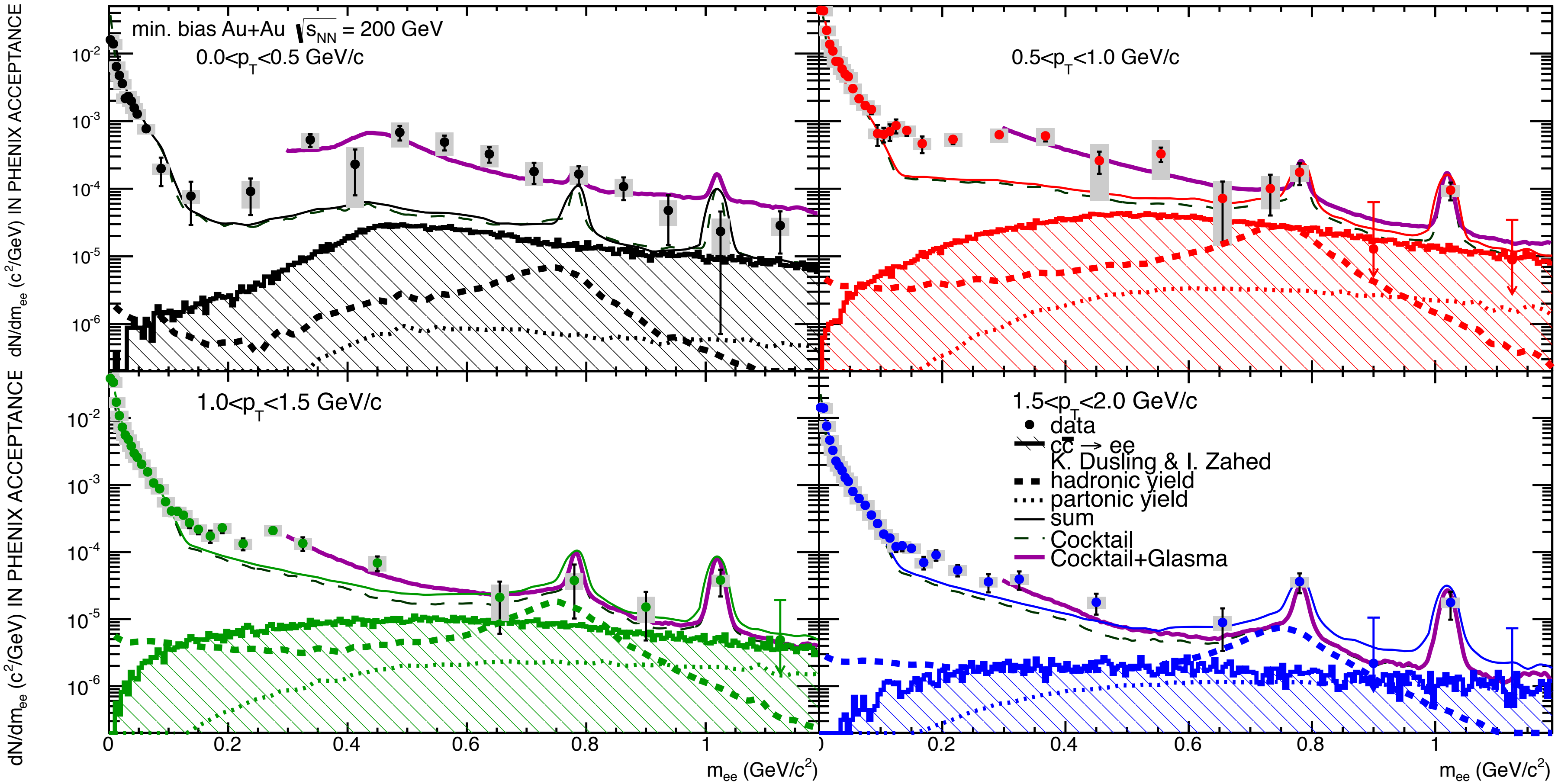
$$N_{quark} \sim \Lambda^3$$

At thermalization

$$\alpha_s \Lambda = \Lambda_s$$

Initially, gluons dominate but at thermalization the number of quarks is of the order of the number of gluons

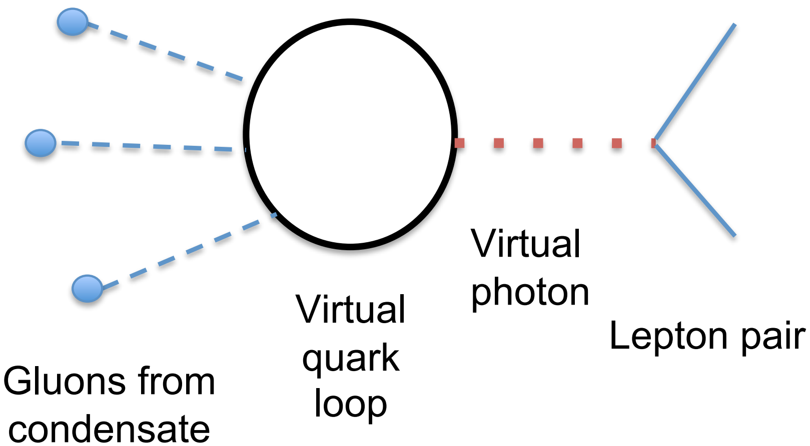
Some enhancement of flow but probably not enough



Phenix measures a large enhancement at small p_T in intermediate mass range

Star has small enhancement, not greatly enhanced for small pT. Star result probably can be explained by oridnary emission processes from either a Glasma or thermalized QGP

What would we need to do in order to get an enhancement at low p_t from the Glasma



Decay from a gluon condensate?

Low pT is naturally enhanced

(Could also be any condensate as well)

Naturally get the power law mass dependence needed to fit the dilepton data

Centrality dependence?

Summary:

The photon date is inconsistent with a thermal explanation
Glasma is natural candidate at high pT of photons, and naturally explains features of the data, but photon flow is a common problem

Star vs Phenix for dileptons must be sorted out. If Phenix is correct and dileptons have a strong enhancement at low pT, some sort of condensation phenomenon is suggested opf which the Glasma provides candidate